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(19)

(54) IMPROVEMENTS RELATING TO METHODS OF AND APPARATUS FOR FRICTION WELDING

(71) We, CLARKE CHAPMAN—JOHN THOMPSON LIMITED, a British Company, of Victoria Works, Gateshead, in the County of Durham NE8 3HS do hereby declare the invention for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement

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In relation to this method as hitherto generally practiced, one serious objection is that portions of the faces furthest removed from the axis of rotation are subjected to a much higher relative rubbing velocity with respect to each other than are portions of the faces situated nearer to the axis of rotation, and indeed in coincidence with the axis there is no relative rubbing between the faces. Consequently it is difficult to ensure that each element of the material adjacent to the faces of the workpieces reaches a temperature proper to enable effective fused union to be established between the workpieces over the entire areas of the faces.

The problem of ensuring that each element of the material adjacent to the faces of the workpieces to be joined reaches such a proper temperature is even greater in cases where it is desired to join workpieces, one or both of which presents a non-circular face at a site at which it is desired to form a welded junction by the method mentioned above.

Another problem ...

ERRATUM

SPECIFICATION No. 1,324,431

Page 7, line 57, *for* ROBERT J. CUMINGS *read* ROBERT J. CUMMINGS

THE PATENT OFFICE
7th January, 1974

One object of the present invention is to provide a new or improved method of friction welding and an apparatus for carrying such method whereby one or more of the above mentioned disadvantages are eliminated or reduced.

A further requirement which militates against the joining together by the method described above of two workpieces of non-circular cross-section is that it is normally necessary to form the junction between such workpieces whilst the latter are held in a predetermined proper orientation relative to each other. This cannot conveniently be effected if the method previously described is used to form a welded junction.

A further object of the invention is to provide a new or improved method of friction welding by means of which work-

SEE ERRATA SLIP ATTACHED

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(71) We, CLARKE CHAPMAN—JOHN THOMPSON LIMITED, a British Company, of Victoria Works, Gateshead, in the County of Durham NE8 3HS do hereby declare the invention for which we pray that a Patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a method of and apparatus for effecting friction welding of workpieces to establish a welded junction between them.

Hitherto friction welding has generally been effected between workpieces by holding the workpieces with respective faces thereof situated at the site at which the welded junction is required to be formed, in contact with each other over said faces, and subjecting the workpieces to relative rotation about an axis at right angles to the faces, continuing the rotation until the material of the workpieces adjacent to said faces has been raised to a temperature at which it is possible to establish a fused union, and then stopping the relative rotation while continuing to exert relative axial pressure between the contacting faces to cause the union to take place.

In relation to this method as hitherto generally practiced, one serious objection is that portions of the faces furthest removed from the axis of rotation are subjected to a much higher relative rubbing velocity with respect to each other than are portions of the faces situated nearer to the axis of rotation, and indeed in coincidence with the axis there is no relative rubbing between the faces. Consequently it is difficult to ensure that each element of the material adjacent to the faces of the workpieces reaches a temperature proper to enable effective fused union to be established between the workpieces over the entire areas of the faces.

The problem of ensuring that each element of the material adjacent to the faces of the workpieces to be joined reaches such a proper temperature is even greater in cases where it is desired to join workpieces, one or both of which presents a non-circular face at a site at which it is desired to form a welded junction by the method mentioned above.

Another problem which is encountered is that since an effective fused union can take place only if relative rotation between the workpieces is discontinued, and the interval of time elapsing between attainment so far as possible of a proper temperature in layers of material adjacent to the faces to effect fused union between them, and cessation of relative rotation, should be kept to a minimum, it has hitherto been necessary to provide powerful brake means to ensure that relative rotation is discontinued in the required short interval of time.

Not only does such brake means require to dissipate a large quantity of energy when ever it is brought into operation, but there is obviously a great wastage of power in operation of the apparatus, since the rotating parts must repeatedly be brought up to a proper speed of relative rotation and then subjected to braking.

One object of the present invention is to provide a new or improved method of friction welding and an apparatus for carrying such method whereby one or more of the above mentioned disadvantages are eliminated or reduced.

A further requirement which militates against the joining together by the method described above of two workpieces of non-circular cross-section is that it is normally necessary to form the junction between such workpieces whilst the latter are held in a predetermined proper orientation relative to each other. This cannot conveniently be effected if the method previously described is used to form a welded junction.

A further object of the invention is to provide a new or improved method of friction welding by means of which work-

SEE ERRATA SLIP ATTACHED

pieces, one or each of which has a non-circular cross-section, can be united with each other.

According to the present invention there is provided a method of friction welding workpieces together wherein the workpieces are brought into contact with each other over respective plane faces thereof situated at the site of the welded junction to be formed between them, and are subjected while in rubbing contact with each other to relative translatory movement along an orbital path generated by combining with each other two geometrically similar primary movements executed eccentrically and in like rotational senses about respective axes, and bringing about a discontinuance of said relative translatory orbital movement by phase shifting one of the primary movements relative to the other to an extent to reduce the combined eccentricity of these primary movements to zero when the temperature of layers of material in the workpiece adjacent said faces reaches a value at which a fused union can be formed between the workpieces under continued pressure at said faces.

In a preferred manner of carrying out the method, both of the primary movements are circular movements in one of these movements having an eccentricity equal to that of the other so that the combined eccentricity can be reduced to zero by phase shifting one of the primary movements by 180° relatively to the other.

One of the workpieces may be held stationary and the whole of the translatory orbital movement may be imparted to the other workpiece which is preferably subjected to torque anchoring to maintain it in a substantially constant attitude. It is not excluded, however, that some component of rotational or oscillatory movement about an axis parallel to or coincident with one of said axes be applied to one or both of the workpieces in combination with the translatory orbital movement.

Also, according to the invention, we provide an apparatus for carrying out the method of friction welding in accordance therewith, such apparatus comprising a body or supporting structure, holders thereon for supporting respective workpieces in positions with said plane faces of these workpieces situated at the site of the welded junction to be formed between them and in contact with each other, means for maintaining contact pressure between said faces, and drive means arranged for generating geometrically similar primary motions eccentrically about respective axes and for applying these primary motions to produce relative translatory orbital movement of said holders, said drive means including phase shift means for varying the relative phase of the primary motions in such a manner as to reduce the eccentricity of the translatory orbital motion to zero.

The preferred means for generating the primary motions comprises two eccentric elements rotatable in the same sense about their respective axes, one being carried by the other, and being adjustable angularly relatively thereto by the phase shift means and transmitting its resultant translatory orbital motion to an associated one of the holders.

A further feature of the invention if the provision of balancing means for the eccentric elements which are so arranged that in each position of angular adjustment the net out-of-balance rotating force, due to the eccentric elements and associated balancing means, is substantially equal and opposite to the out-of-balance rotating force, due to the holder and workpiece. Thus counterbalance weights may be provided on each eccentric element adjustable in magnitude and/or radial position by amounts such as to produce the required out-of-balance force to compensate that of any given combination of holder and workpiece.

The invention will now be described, by way of example, with reference to the accompanying drawings wherein:

FIGURE 1 is a diagrammatic representation of an apparatus according to the invention which also illustrates the method of the invention, parts of the apparatus being shown in relative positions providing zero resultant eccentricity, and

FIGURE 2 is a fragmentary view showing some of the parts of Figure 1 in relative positions which provide maximum resultant eccentricity.

Two workpieces which are required to be friction welded together are indicated in Figure 1 and W1 and W2, the workpieces having plane end faces 1 and 2 respectively at which the welded junction is to be formed. For convenience of illustration the workpieces are shown in Figure 1 as being separated from the apparatus, and are omitted entirely from Figure 2, but it will be understood that one of the workpieces, namely W2, will be supported in a suitable holder (not shown) which may be of known construction. This holder is carried on a supporting body, represented diagrammatically at 4, and is arranged for limited movement towards and away from the other workpieces W1 along a reference axis 3. Pressure-applying means would be associated with the holder of the workpiece W2 for establishing the necessary contact pressure between the end faces 1 and 2 of the workpieces. Preferably, the holder carrying the workpiece W2 is arranged to restrain the latter against translatory movement in directions transverse to the

axis 3 and against rotation about that axis.

The workpiece W1 is carried in a further holder represented at C, this holder being supported in a manner to be described hereinafter for movement relative to the body 4 in a circular path about the reference axis 3. The holder C is restrained against movement in a direction along the axis 3 and away from the workpiece W2 so that the necessary contact pressure can be established between the faces 1 and 2.

For clarity of illustration the radius or throw of the translatory orbital motion relative to the dimensions of the end faces 1 and 2 has been exaggerated in the accompanying drawings. In general, the throw will be a relatively small fraction of the smallest cross-sectional dimension of the workpieces W1 and W2, or of the larger of these if they are of unequal size in cross-section. In the case illustrated in the accompanying drawings, where the workpieces are both of circular cross-section and have the same diameter, the radius or throw of the translatory orbital motion may be up to one half the radius of each workpiece.

It will be understood that, although for convenience workpieces of circular cross-section have been illustrated, the invention is applicable also to the welding together of workpieces of non-circular cross-section, for example square or rectanglar section, and is applicable also to the welding of both solid cross-section workpieces and hollow cross-section workpieces, for example tubular workpieces.

The translatory orbital motion of the holder C is generated by two primary motions derived from primary eccentric elements A and B.

The outer eccentric element A is journalled on the body 4 for rotation about the reference axis 3 and has a circular aperture in which the inner eccentric element B is mounted, the centre of this aperture being displaced by a predetermined value or eccentricity *e* from the axis 3.

The eccentric element B also has an aperture in which the holder C is mounted, this aperture also being of circular form and being displaced from the centre of the eccentric element B by the same eccentricity *e*. Typically, the eccentricity *e* is in the region of .06 inches.

Both of the eccentric elements A and B and the work holder C may be of generally tubular form, the wall thickness of each of the elements A and B varying uniformly from a maximum value at one side of the axis 3 to a mimimum value at a diametrically opposite position. Suitable bearing means would be provided between the inner face of the element A and the outer face of the element B, and also between the inner face of the element B and the work holder C. Also the ends of the eccentric element B and of the work holder C which are remote from the workpiece W2 may be closed, and suitable thrust bearings provided to transfer axially directed forces applied from the workpiece W2 to the workpiece W1 through the work holder C, eccentric elements A and B to the body 4. Alternatively, or additionally, the work holder C may be provided with a flange having an axially directed face which co-operates through a thrust bearing with an annular part of the body 4 to prevent displacement of the work holder C along the axis 3. It will be apparent that each of the eccentric elements A and B and the work holder C can rotate relative to the others.

The apparatus further includes drive means, to be described hereinafter, for rotating the eccentric elements A and B in the same rotational sense about the axis 3, as indicated by arrows 5 and 6 in Figure 1. If the respective angular velocities of the eccentric elements A and B are equal, and the relative position is hereinafter referred to as the datum position, the centre of the work holder C will remain stationary on the axis 3. If the angular velocities of the eccentric elements are equal, but the phases of these elements are displaced relative to one another from the datum position, the work holder C will move along a circular path about the axis 3, the radius or throw of this path depending upon the phase displacement of the eccentric elements. As shown in Figure 2, the maximum radius or throw of the orbital path of the work holder C is 2*e* and the relative position of the eccentric elements which produces this is such that the thinnest wall portion of both elements lies on the same side of the axis 3.

It will be seen from Figure 1 that in the datum position of the eccentric elements A and B, the thickest wall section of one element lies on the same side of the axis 3 as the thinnest wall section of the other element.

Rotation of the work holder C relative to the body 4 is restrained by a torque anchor means represented at 30. The torque anchor means may comprise an arm which is attached to and projects radially of the work holder C, and includes at its free end a part-cylindrical or part-spherical head which engages in a parallel sided socket formed in the body. Such an arrangement would provide for limited pivoting movement and translatory movement of the head relative to the body during movement of the work holder C along the orbital path about the axis 3. However, the torque anchor means would ensure that when the centre of the work holder C coincides with the axis 3, the workpiece 1 assumes a predetermined attitude relative to the workpiece W2. It will

be appreciated that limited rotational movement of the work holder C and workpiece W1 relative to the body would occur during orbital motion, but such rotation would be controlled by the torque anchor means.

The drive means of the apparatus comprises an electric or other form of motor 10 which is supported on the body 4. The motor drives an output shaft 11 which conveniently is supported in bearing means on the body for rotation about the axis 3. Drive is transmitted from the motor 10 to the eccentric elements A and B through the intermediary of two epicyclic gear assemblies 7 and 8 respectively.

The epicyclic gear assembly 7 comprises an annulus 12 which is rigidly connected to, and at least partly supported by, the shaft 11. The annulus 12 has internal teeth which mesh with axially spaced planetary gears 15 and 16, the space between which is exagerated in Figure 1 for clarity. The planetary gear 15 is carried on an annular carrier 17 which is mounted on either the body 4 or the annulus 12 for rotation about the axis 3. As shown in Figure 1, the carrier 17 is conveniently situated outside but adjacent one end of the annulus 12. The planet gear 15 also meshes with a sun gear 13 which is carried on and keyed to a shaft 20.

The planet gear 16 is carried on a fixed support 18 which is mounted on the body 4 so that the planet gear 16 remains in a fixed position relative to the body. The planet gear 16 is, however, free to rotate in accordance with movements of the annulus 12. The planet gear 16 also meshes with a further sun gear 14 which is carried on and keyed to a hollow shaft 21 which is co-axial with the shaft 20. These shafts may be arranged to provide further support for the epicyclic gear assembly 7.

The respective axial dimensions of the planet gears 15 and 16, and of the sun gears 13 and 14 are each slightly less than one half the axial dimension of the annulus 12.

The sun gears 13 and 14 have the same number of teeth as each other, as do also the planet gears 15 and 16. Accordingly, the co-axial shafts 20 and 21 will be driven rotationally at the same speed and in the same rotational sense, provided that the carrier 17 remains stationary.

Although for convenience of illustration single planet gears are shown co-operating with each of the sun gears 13 and 14, it will be understood that the carrier 17 may be provided with two or more planet gears for co-operation with the sun gear 13, and two or more stationary planet gears may be provided for co-operation with the sun gear 14.

The epicyclic gear assembly 8 comprises a sun gear 26, a planet gear 27 and an internally toothed annulus 28. The planet gear 27 is rotatably mounted on a carrier 31 which in turn is drivingly connected with the outer shaft 21. The planet carrier 31 is also drivingly connected with the outer eccentric element A, as shown at 23. The carrier 31 is supported on the eccentric element A and may include a sleeve-like portion which surrounds the epicyclic gear assembly 8, and a radially extending portion which interconnects the outer shaft 21 and the sleevelike portion.

The annulus 28 is rigidly connected to an end of the inner shaft 20, and the sun gear 26 is connected with an adjacent end of the eccentric element B by means of a spline connection which permits of sliding movement of the eccentric element B relative to the sun gear 26 in a direction transverse of the axis 3, whilst ensuring that the eccentric element B rotates with the sun gear 26. The eccentric element B extends through an aperture in the end of the eccentric element A which is remote from the workpiece W2.

Whilst the planet carrier 31 and the annulus 28 are rotated at the same speed and in the same direction, the sun gear 26 will also rotate at the same speed and in the same direction as both these parts, with the consequence that the eccentric elements A and B will be driven in the same direction and at the same speed.

Phase shift means is provided for producing a phase shift of the eccentric element B relative to the eccentric element A. The phase shift means is arranged to cause part-rotational movements of the planet carrier 17 and conveniently comprises a rack having teeth which engage with further teeth provided on the carrier 17, the rack being mounted on the body 4 for reciprocation transversely of the axis 3 to effect phase shifting. Alternatively, the phase shifting means may comprise a piston and cylinder assembly, one element of which is fixed relative to the body, and the other element of which is connected with an arm projecting radially from the carrier 17 so that extension and contraction of the piston and cylinder assembly causes part-rotational movements of the carrier. In a further alternative construction the phase shifting means comprises a screw mechanism. Appropriate indicator means may be associated with the phase shift means to provide an indication of the phase of the eccentric element B relative to the eccentric element A.

The phase shift means operates as follows. The carrier 17 is rotated in one direction or the other about the axis 3 for a fraction only of one revolution. Depending upon the direction of movement, the sun gear 13 and

therefore the inner shaft 20 will temporarily be speeded up or slowed down relative to the annulus 12 and the outer shaft 21. Accordingly, the annulus 28 will be speeded up, or slowed down temporarily relative to the carrier 31 and this will result in a temporary speeding up or slowing down of the sun wheel 26 and eccentric element B relative to the eccentric element A.

In a typical construction, the annulus 12 has 58 teeth, the sun gears 13 and 14 each have 20 teeth, and the planetary gears 15 and 16 each have 19 teeth. The annulus 28 has 48 teeth, the planetary gear 27 has 15 teeth and the sun wheel 28 has 20 teeth. With this construction, in order to produce a 180° phase shift between the sun gear 26 and the carrier 31, and hence between eccentric elements A and B, the planet carrier 17 must be displaced through an angle of 19¼ degrees. It will be appreciated that the carrier 17 cannot be rotated through a complete revolution owing to the presence of the planet gear 16 and the support 18.

In carrying out the method of the invention using the apparatus hereinbefore described, the workpieces W1 and W2 are initially brought into contact over their end faces 1 and 2 whilst the eccentric elements A and B occupy the datum position illustrated in Figure 1. The workpiece W2 is urged in to contact under pressure with the workpiece W1 and whilst this pressure is maintained the phase shift means is operated to bring about a relative phase shift between the eccentric elements A and B so that the work holder C and the workpiece W1 supported thereby travel translationally along an orbital path.

When the temperature of the metal in the layers adjacent to the faces 1 and 2 has reached a value at which a welded union can take place, the phase shift means is again operated to bring the eccentric elements A and B back to the datum position, and the contact pressure between the workpieces is at least maintained, and preferably increased to cause the welded junction to be formed.

The form of drive means herein described enables translatory orbital motion to be carried out at extremely high speed. Typically, the output shaft 11 of the motor is driven at a speed in the region of 4,000 r.p.m. and this produces a speed of about 12,000 r.p.m. in respect of the planet carrier 31 and the annulus 28 so that both eccentric elements A and B rotate at this speed. Accordingly, about 12,000 cycles of orbital motion of the workpiece W1 will take place in a minute.

The workpieces may be like or unlike metals having welding compatibility. The welding parameters, such as the period of relative movement, the contact pressure during the initial or burn-off stage during which movement occurs, and the contact pressure during the second or forging stage, which are necessary to produce a satisfactory welded junction between various metals are well known to those expert in the art.

If facilities for varying the speed of the eccentric elements A and B are required, a variable speed gearbox may be included between the motor 10 and the output shaft 11.

Due to the extremely high speed of orbital movement of the holder C1, it is desirable that the rotary out-of-balance force, due to the weight of the holder and the workpiece supported thereby, should be compensated wholly or to a substantial extent.

One manner of accomplishing this is to provide on each of the eccentric elements A and B, a counterbalance weight. The mass of the counterbalance weight carried on eccentric element A multiplied by the distance of the centre of gravity of this weight from the reference axis should be equal to the mass of the counterbalance weight associated with the eccentric element B multiplied by the distance of the centre of gravity of this weight from the reference axis, and the sum of these quantities should be equal to the combined mass of the holder C and the workpiece multiplied by the distance of the combined centre of gravity of these two parts from the reference axis.

The counterbalance weights would be so arranged that when the eccentric elements are in the relative datum position, the respective counterbalance weights are disposed on opposite sides of the reference axis, whilst when the eccentricity of the orbital path of the holder C is a maximum, the counterbalance weights lie on the same side of the reference axis and the combined counterbalance force produced by the counterbalance weights will be a maximum. Accordingly, a fully counterbalanced condition is maintained in all positions of relative adjustment of the two eccentric elements.

It will be apparent that the mass or distances from the reference axis of the counterbalance weights will be required to be changed if the workpiece is replaced by a further workpiece having a different mass.

An alternative expedient to provide adjustment of the counterbalance weights according to the mass of the workpiece is to split each counterbalance weight into two portions which are mounted adjustably on the eccentric element concerned. Each portion would consist of a segment which can be overlapped to a variable extent with its companion segment. Fully overlapping relationship provides maximum effective

value of the counterbalance weight and relative angular adjustment in opposite directions reduces the value. Markings may be provided on each of the eccentric elements providing a scale calibrated in terms of the mass of the workpiece to be handled.

In a further alternative, a compensating dummy workpiece could be inserted in the holder C inwardly of the workpiece W1 so that the combined mass of the workpiece W1 and the dummy workpiece is equal to that for which fixed value balance weights have been provided.

It will be apparent that instead of holding one workpiece stationary and applying two components of eccentric motion to the other workpiece, a first component of eccentric motion could be applied to one workpiece whilst a second component of eccentric motion is applied to the other workpiece. Phase adjustment of the two eccentric motions would provide relative orbital movement between the workpieces as required.

If required, the two orbital movements could be non-circular, for example elliptical, providing that the two motions are geometrically similar so that by appropriate phase adjustment the aggregate motion can be reduced to zero.

WHAT WE CLAIM IS:—

1. A method of friction welding workpieces together wherein the workpieces are brought into contact with each other over respective plane faces thereof, situated at the site of the welded junction to be formed between them, and are subjected while in rubbing contact with each other to relative translatory movement along an orbital path generated by combining with each other two geometrically similar primary movements executed eccentrically and in like rotational senses about respective axes, and bringing about a discontinuance of said relative translatory orbital movement by phase shifting one of the primary movements relative to the other to an extent to reduce the combined eccentricity of these primary movements to zero when the temperature of layers of material in the workpieces adjacent said plane faces reaches a value at which a fused union can be formed between the workpieces under continued pressure at said faces.

2. A method according to claim 1 wherein both of the primary movements are circular movements, one of these movements having an eccentricity equal to that of the other primary movement, so that the combined eccentricity can be reduced to zero by phase shifting of one of the primary movements by 180° relative to the other.

3. A method according to claim 1 or claim 2 wherein one of said workpieces is held stationary and the whole of said relative translatory movement is applied to the other workpiece.

4. A method according to any preceding claim wherein at least one of said workpieces is arranged for limited rotation about an axis parallel to or coincident with one of said axes, and is subjected to torque anchoring to control such rotation in a manner such that when said relative translatory movement ceases, the workpieces adopt a predetermined attitude to each other.

5. Apparatus for carrying out the method according to claim 1 of friction welding together workpieces having respective plane faces at which the welded junction is to be formed, such apparatus comprising a body, holders thereon for supporting respective workpieces in positions with said plane faces situated at the site where the welded junction is to be formed and in contact with each other, means for maintaining contact pressure between said faces, and drive means arranged for generating geometrically similar primary motions eccentrically about respective axes and for applying these primary motions to produce relative translatory orbital movement of said holders, said drive means including phase shift means for varying the relative phases of the primary motions in such a manner as to reduce the eccentricity of the translatory orbital movement to zero.

6. Apparatus according to claim 5 wherein the drive means comprises two eccentric elements rotatable in the same sense about their respective axes, one eccentric element being carried by the other and being adjustable angularly relative thereto by said phase shift means, so that the respective primary motions produced by rotation of said eccentric elements are applied to the same holder.

7. Apparatus according to claim 6 wherein said one holder to which the primary motions are applied is carried on said one eccentric element for rotation relative thereto, and torque anchor means is provided for so controlling such rotation of said one holder that the latter assumes a predetermined attitude relative to the other holder when the eccentricity of the translatory orbital motion is reduced to zero.

8. Apparatus according to claim 7 wherein said torque anchor means comprises an arm projecting radially from the holder, an end of the arm remote from the holder being held in a substantially fixed position on the body.

9. Apparatus according to claim 7 or claim 8 wherein each of the eccentric elements is of generally sleeve-like form, having a cylindrical outer surface and a cylindrical inner surface eccentric with respect to the outer surface, and said one eccentric element is mounted within the

other eccentric element and receives said one holder.

10. Apparatus according to any of claims 6 to 9 wherein the drive means comprises an epicyclic gear train for transmitting drive from a common source to both of said eccentric elements.

11. Apparatus according to claim 10 wherein said epicyclic gear train comprises a sun gear and an annulus each meshing with a common planet gear, said one of the eccentric elements is connected drivingly with the sun gear, said other of the eccentric elements is connected drivingly with a carrier of said planet gear, the annulus is arranged to be driven at a predetermined uniform speed, and the planet gear carrier is arranged to be driven at a speed which can be varied temporarily by said phase shift means.

12. Apparatus according to any of claims 6 to 11 wherein said one holder is constrained against movement in a direction away from the other holder, and the latter is arranged for movement towards said one holder under the action of said means for maintaining contact pressure between the faces.

13. Apparatus according to any of claims 6 to 12 wherein balancing means is provided in association with each of the eccentric elements and is so arranged that the net out-of-balance rotating force due to the eccentric elements and their associated balancing means varies in accordance with the eccentricity of said translatory orbital motion of the holders, and is eliminated when relative motion of the holders ceases.

14. Apparatus according to claim 13 wherein one or more balancing weights is provided on each of said eccentric elements, the respective positions of said balancing weights being adjustable radially of the axis of their associated eccentric element.

15. A method of friction welding workpieces together substantially as herein described with reference to and as illustrated in the accompanying drawing.

16. Apparatus for friction welding together workpieces substantially as hereinbefore described with reference to and as illustrated in the accompanying drawing.

17. An article comprising parts united by fusion by a method according to any of claims 1 to 4 and 15, or by use of apparatus according to any of claims 5 to 14 and 15.

ROBERT J. CUMINGS,
Chartered Patent Agent,
Agent for the Applicants.

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1324431 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

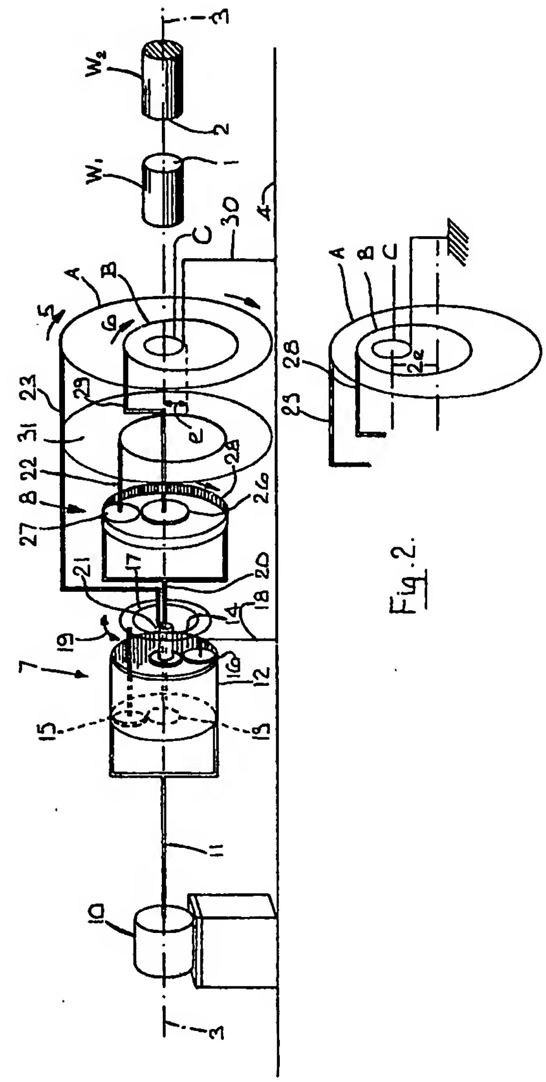

Fig. 1.

Fig. 2.